Development and Manufacture of Electroformed Conductor for Telephone Drop Wire

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Telephone drop wire is that familiar black overhead wire which brings the telephone service to the home. It is a parallel pair of conductors separated and positioned in an extruded insulation, covered by a cotton serving and jacketed with a neoprene compound of tire tread-like qualities. In the past, a cast copper jacketed steel ingot, rolled and drawn to size, has been used to provide a wire that combines high strength and good conductivity. In order to assure more than a single source of supply and to provide improved mechanical and electrical characteristics, a completely new plant has been constructed for continuous plating of steel wire at completed size. This process provides a stronger, yet smaller and, therefore, less costly wire than was possible previously. Plating is done at 100 feet per minute on 25 wires simultaneously. The conductor is then processed as formerly to provide the neoprene jacketed drop wire.

HISTORICAL BACKGROUND

It has been customary in manufacture to apply a lead and a brass plate to drop wire conductor to secure good adhesion to the insulating compound. The brass provides the adhesion while the lead prevents attack on the copper by the sulfur in the rubber. In 1941, two tandem lead and brass plating machines were placed in service at the Point Breeze Works of the Western Electric Company to apply these coatings on a production basis. Their successful operation proved that electrolytic deposition of two metallic coatings in tandem at high speed was commercially practicable. It was not difficult to imagine the addition of a copper plating section to deposit copper, in addition to lead and brass, on a steel wire as a combined operation. The technical problems involved,

however, were of considerable magnitude, and their successful solution required a substantial amount of investigation and development.

Such a process appeared to offer a number of attractive features. The maximum strength of the steel core could be utilized since no compromise in physical properties would be required to permit rolling and drawing. A highly uniform cross section could be secured which would provide continuous copper protection for the steel core against corrosion. Since the steel core wire would be a standard commercial item available from a number of manufacturers, alternate sources would be available to assure continuity of supply.

There were also substantial economic inducements. The higher strength wire of uniform construction would reduce the cost of trouble calls to the Bell System. It appeared that a plant could be designed which would require no more labor to operate than was required for the existing lead-brass plating operation. By starting with a steel wire of uniform and circular cross section and applying a uniform copper jacket, the desired physical and electrical requirements could be met by a conductor 2-½ thousandths smaller in diameter, which would, in turn, reduce the overall dimension of the finished product. Although this reduction might appear small, the very large footage of wire required indicated a saving of a half-million pounds of copper a year, and a combined saving of steel, copper, rubber, cotton and neoprene, all strategic materials, of a million pounds a year. Combined savings to the Bell System Operating Companies and Western Electric Company were estimated at better than one million dollars a year.

World War II prevented further work until 1946 when the project was reopened and methods of obtaining heavy copper deposits investigated on a laboratory scale. Initial developments showed promise and late in the year, a separate development laboratory was set up to investigate various electro-chemical problems and to develop information on which a pilot plant could be designed. The term "Electroforming" was first applied at this time because it was apparent that the process was not to be one of electroplating in the ordinary sense but rather was to substantially change the physical and electrical properties of the wire. In other words, the terminology was intended to differentiate between utility and what are usually decorative or protective functions.

A pilot plant was built and installed which operated successfully the first day it was placed in operation. The results obtained on the pilot machine exceeded expectations. The limiting current density for the acid copper plating solution determined in the laboratory was 1,000 amps./sq. ft., whereas 2,000 amps./sq. ft. was realized on this machine. This in-

crease in current density meant a rate of deposition double that which had been predicted.

On this pilot machine the operating limits of the various plating and cleaning solutions were established. Methods of control, materials of construction and design features were evaluated. A field trial lot of 200,000 linear feet of drop wire and numerous samples of wire were processed for examination and design approval.

Some time was spent in making the basic plant decisions, evaluating pilot plant experience and carrying through the numerous special investigations required to guide the engineering design. The detailed engineering and drafting were begun and firm orders placed for equipment.

DESIGN PREMISES

Certain design premises became apparent from experience with the pilot plant. The nature of the process dictated continuous operation on a three-shift, seven-day basis. To secure such operation, it was necessary to duplicate certain critical facilities, use the largest practical reel size for maximum wire run time and to employ great care in the design of the wire handling equipment to minimize wire breaks. The second premise was low maintenance. This required that the materials in contact with the various chemicals could be selected only on the basis of extensive corrosion tests. This involved the study of many of the grades of stainless steel as well as the rarer metals and the broad field of plastics and elastomers to select suitable materials for tank lining, machine parts, and piping.

Substantially automatic operation was set up as another design objective. This, of course, involved the isolation of the factors requiring control and selection of the most suitable means. The safeguarding from waste of valuable solutions was a fourth consideration. Spare tank capacity was provided in case any of the storage tanks developed leaks and had to be repaired. Facilities were required to recover electrolyte carried out from plating operations by the wires themselves. Means had to be provided for recharging and reconditioning the various electrolytes. Still another premise was the permanency of solution: no dumping and replacing of plating solution was contemplated. And, of course, safety to personnel was a must. In addition to the usual hazards from acids and alkalis in a chemical plant, accidental mixture of electrolytes could give rise to highly poisonous gases. This necessitated the selection of highly reliable piping materials and the provision of adequate employee protective devices and routines.

BASIC PROCESS

The starting point in the process is commercial improved plow steel wire 0.0336″ in diameter delivered on 450-pound reels. Twenty-five strands pass through the plating machine in parallel at 100 feet per minute. After suitable cleaning, approximately 2-½ thousandths of copper plus a thin plate of lead and brass are electrolytically deposited on the wire. To apply this deposit requires nine different electrolytes, approximately 80,000 amperes at 5 volts, and a 600-ft machine with a wire span from supply to take-up of 850 feet.

The plating portion of the machine is a relatively simple structure consisting of a long trough containing plating cells alternating with contact rolls. The electrolytes are pumped into the plating cells through which the wire passes, cascade into return troughs, flow back to reservoirs and are continuously recirculated. The contact rolls position and propel the wires through the machine and serve as the means of making electrical contact.

The general structure of the machine is uniform throughout, only the material changing to fit the chemical requirements of the electrolyte in the particular section. The wire, in passing from one electrolyte to another, travels through washing and wiping facilities mounted in the troughs to prevent contamination of electrolytes and reduce dragout of valuable solutions. The finished wire, controlled to specified conductivity, is then taken up on reels ready for insulating.

THE BUILDING

The building is 91 feet wide by 340 feet long, of brick and steel construction, in keeping with Point Breeze architecture. It was specifically designed to fit the process. The first floor is given over to wire supply and take-up, electrolyte mixing, pumping and conditioning and material storage. All plating operations take place on a mezzanine. The upper portion of the building is divided into three bays by a pair of lengthwise partitions. The center section contains the two plating machines, each machine being constructed in the form of the letter "C", the two "C" shaped machines being placed face to face. The outer bays contain the rectifiers, electrical controls and heating and ventilating equipment. The floor of these bays is steel grating. The partitions prevent the entrance of any vapors released by the heated plating solutions, and the ventilating equipment forces a steady stream of clean and tempered air downward over the electrical facilities and through the grating into the first floor area below.

The ventilating equipment draws in fresh air from the roof, heats it

if required, and distributes it down the electrical bays by means of overhead ducts. The system operates under modulating temperature control with 100 per cent fresh air make-up. After reaching the first floor, the air then flows upward through the center section of the building, past the plating machines and is exhausted through the roof by fans at the rate of 160,000 cubic feet per minute.

Power for the building is supplied from a substation located in the south electrical bay. A pair of underground cables bring in energy at 13,200 volts to high-voltage switches for distribution to two identical, 1500 kva, three-phase transformers where it is stepped down to 480 volts before entering low voltage switch gear for distribution about the building. The electrical system is designed so that the entire plant load can be supplied by either of the high-voltage cables and for a short period of time by eitber of the step-down transformers. Steam, city water and house water are furnished through an underground tunnel.

In addition to electric power, the building is furnisbed with 150 lb./sq. in. steam for process aud heating, 90 lb./sq. in. compressed air for control instruments and various process functions, city water and house water. A sanitary sewer for the washrooms plus separate acid and alkali sewers of chemical resistant pipe have been provided from the pits where the electrolyte storage tanks are located. These latter sewers are for emergency use only. All solutions are reconditioned aud recirculated in normal operation and as tbe plating solutions are permanent no disposal plant has been deemed necessary.

Lighting throughout tbe plant is furnisbed by incandescent lamps in simple porcelain reflectors, designed to give a minimum of 17 foot candles at all locations. This is supplemented hy fluorescent fixtures at the take-up stands because experience has shown that appearance of tbe wire on the take-up reels is an important indication of the quality of the plate. The entire interior of the plant, as well as all machinery, is finished with vinyl base paint. Extensive tests were made of various types of chemical resistant finishes and the vinyls were found to be the outstanding performers.

For moderate service conditions, metal surfaces were wire brushed and washed down with cleaning solution before the wash type primer was applied. For severe service, the surfaces were cleaned by sand blasting before priming. Tbe customary primer coat was then applied and several top coats, the number depending upon tbe severity of the service.

WIRE HANDLING EQUIPMENT

Tonnage-wise the steel core wire is the largest, if not also the most important, single item of raw material procurement. In searching the

market for a high-strength, bright finish steel wire which would be readily available from a number of supply sources, it was found that improved plow steel wire as regularly used in wire rope manufacture would meet the proposed requirements and could be purchased under the several wire mills' own control specifications and tolerances, giving Western the reliability of an established commercial supply without the price premiums for a specialty wire.

In only one important particular was it found expedient to deviate from the steel mills' standards as regards the steel core wire, and this specifically concerned the packaging of the wire to facilitate subsequent handling in our plant. It has been customary for the steel mills to ship this type of wire to customers in paper-wrapped bundles which are block-wound, catch-weight coils, shaken down and bound with soft iron tie wire. Because of the coil-forming action on the draw-blocks, the steel wire mills have found that bundles containing more than about 250 pounds of 33-mil wire cannot be made without greatly increasing the dangers of tangling and breaking when wire is payed out from the bundle.

An economic study of wire handling in both the electroforming plant and the subsequent insulating and jacketing departments showed that a 450-pound steel wire package free of splices to avoid excessive scrap, cut-over and reel handling losses was most desirable. It was found impractical to put this much core wire in a single bundle with any assurance that the wire could be payed out of the coil without too many breaks from snarling, tangling and fouling of the wire on the pay-off stands.

After extended negotiations with the suppliers, decisions were made to obtain the core wire on reels, in order to insure reliable pay off from supply units of the weights required. Agreements were reached to handle the wire on returnable reels which the mills provided to suit their own winding equipment. No unwinding problem exists at Western Electric because the supply reel is not rotated to unwind.

The nature of the electroforming and electroplating operations renders it impracticable to stop a running wire to replenish an exhausted supply. Consequently, it was necessary to provide for splicing the inner end of the supply wire paying off onto the outer end of a standby supply. Where the supply reels are revolved to unwind and remove the wire, such provision calls for compensator loops or accumulator towers to accumulate temporarily enough feed-out wire to keep the machine going while a splice to the new supply is being made.

Such accumulator devices require a large amount of space which was not economical to provide. They demand that an operator be precisely on the spot to make the splice before the limited feed-out accumulation

is exhausted, an impractical demand considering the small number of operators assigned to the plant. Furthermore, rotating supply reels of the size under consideration require special feed-off drives and controls to maintain a pay-out drag of an order to establish the range of operating tensions demanded in the plating lines. To circumvent the objectionable features of the rotating supply reels, provision has been made to take the wire off "over end" from a stationary reel, lying flat on one of its heads, so that the inner (or tail) end of the wire paying off can be spliced to the outer (or starting) end of a stand-by at any time before the pay-off length runs out. To this end arrangements were made with the steel core wire suppliers to bring the inner end of the wire to the outside within the reel heads, allowing enough free length for making the splice.

Each of the twenty-five wire channels on each of the electroforming machines is provided with a dual supply stand holding two reels in the immediate vicinity of each other, one the pay-off and the other a stand-by (Fig. 1). When placed in position on the supply stand, the upper heads of both reels are set up with flyers to guide and tension the off-coming wire, and facilitate automatic transfer from one reel to the next. The

Fig. 1 — Steel wire supply stands, two for each of the twenty-five channels on a machine, permit continuous operation. A 450-lb. spool of wire is being positioned by the nearest operator while behind him another operator is electric welding a wire joint.

flyer rotates about an extension of the reel axis and is lightly restrained with a friction drag-brake which prevents flyer overrun and puts just enough tension in the lead-off wire to keep it from flying wild and tangling. The nature of the over end pay-off causes too wide a change in tension as the supply reel is depleted so the flyer braking force is limited and an auxiliary brake sheave is used to supply most of the back-drag on the wire and create a more stable and uniform approach tension to the machine. From this sheave the wire passes through guide tubes to a fanning section which arranges the wires in proper order and guides them to the supply capstan on the mezzanine at the entrance to the plating line (Fig. 2). The supply capstan is of large diameter and strongly electromagnetic and the wire is snubbed to a 140-degree wrap on it to minimize wire slip and creep. The supply end capstan is the speed governor for the entire machine. It is positively driven with a shunt-wound dc motor regulated to hold capstan speed within ½ of 1 per cent over the adjustable wire speed range of 80 to 120 f.p.m. (Fig. 3).

The twenty-five wires of each machine are carried through the plating line in spaced relationship by passing alternately over and under a series

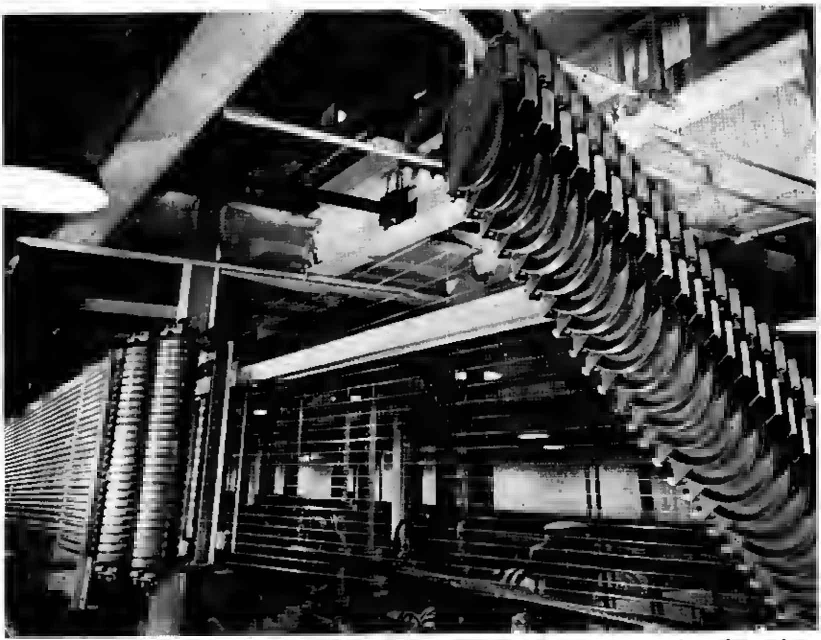

Fig. 2 — String-up of the twenty-five channels of wire carries them from supply spools, left, through guides and sheaves to the mezzanine location of plating operations.

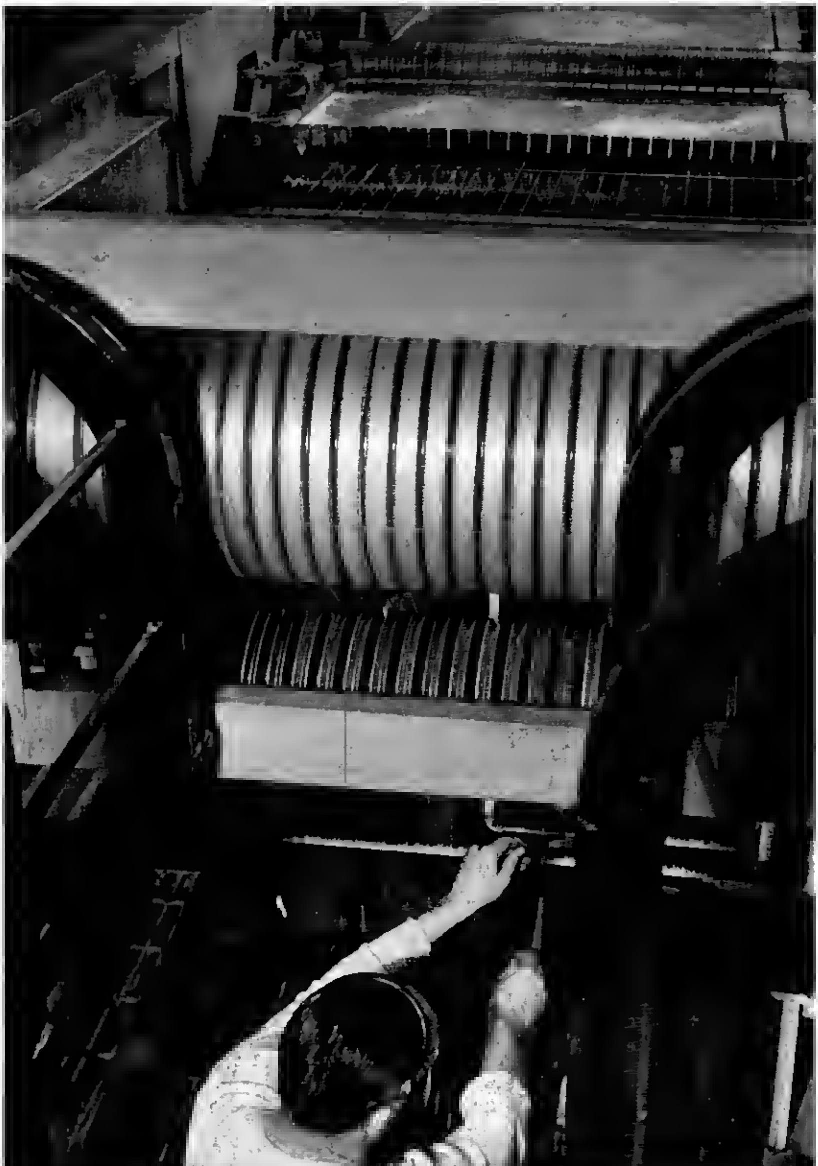

Fig. 3 — Up and over the capstan the steel wires are drawn from the supply position on the first floor to the initial wire preparation baths to begin the 600-ft. journey through the electroforming process.

of grooved rolls. There are a hundred of these rolls in each plating line and all but a very few of them are equipped with contact brushes to supply cathode potential to the wires in the cells. Because of bearing, roll seal, and brush frictiou, these rolls offer considerable resistance to turning; this frictional resistance is subject to rather wide variations under service conditions. To limit and control the rate of wear on the roll grooves, and to prevent a build-up of excessive wire tensions in the plating lines, all rolls are positively driven at constant speeds. The rolls are grouped on eight separate drive units, each powered by its own motor, so that each carries a definite portion of the total roll load. The motors are geared in and speed regulated by resistances in the motor control circuits to drive all the contact rolls a little faster than wire speed, each successive group of rolls being also driven slightly faster than the preceding one. This roll overdrive, as a result of wire-to-roll friction, produces a closely controllable pull on each individual wire since the only service factor affecting roll pull is the total wire tension (the consequent wire-to-roll pressure) prevailing in any given part of the plating line. The roll pull on the wire increases wire tensions toward the entry end of the plating line so that the point of highest wire tension is at the supply capstan recess, but the total increase is moderate because most of the roll pull is absorbed in overcoming wire drag through the cells.

Wire tensions on the approach side of the magnetic supply and capstan are held low in the interest of safety, efficiency and economy. Those on the recess side of the capstan are higher, which means that the capstan is actually pulled by the wire. So that the motor on the capstan does more than just a braking job, it is made to drive the first group of contact rolls, all those in the preparation leg. In this way the supply capstan motor is loaded about the same as other motors in line so that it operates at a comparable point on its characteristic curve, and performs in substantially the same way as the other motors. It is important that this motor be positively loaded so that it "motors" instead of "generates" because this motor drives a tachometer generator which controls the entire drive.

Most of the contact rolls are in the acid leg of the plating line. They are hardest to drive because of their close spacing and the large number of brushes they carry. To safely limit drive chain tensions and produce the desired roll overdrive gradients the acid leg rolls are grouped in six drive units each with its individual motor. These are matched motors with similar load characteristics and they are geared in at comparable

points on their characteristic curves so that they perform alike under speed and load fluctuations.

The finishing leg rolls and the take up capstan are driven with a single motor identical to the motor driving the supply capstan and the preparation leg. The take-up end capstan adds only slightly to the wire tension over and above that produced at the take-up spools. For that reason the take-up capstan alone does not load the drive motor enough to make it perform like the other motors under load and speed changes. To build up the load on this motor to where it performs at a point on its characteristic curve corresponding to the other motors and "follows" properly it is made to also drive all the contact rolls in the finishing leg.

The take-up end capstan at the exit of the plating line, in conjunction with the take-up spool is fundamentally the tension establishing means for the entire plating line.

From the take-up capstan, the plated wire is passed back to the main floor over another fanning section, and through guide tubes to the take-up spools. While the take-up capstan may be said to establish tensions for all of the plating line up to it, it is the take-up spool drive which basically originates and determines the order of wire tensions for the entire machine. Any tension increase or decrease originating at the take-up spool is reflected all the way back through the machine to the magnetic supply capstan (Fig. 4).

On the electroforming machines wire tension control is quite important. If tensions become too low, the wire may intermittently lose contact on the rolls, sag or weave in the plating cells enough to disturb the spacing between the wire cathode and the anode bed in the cell, or actually stall or hesitate long enough to be burned in two at a contact roll. On the other hand, if tensions are permitted to become too high, the tight wire produces excessive wear on the contact rolls, and bruises or scrapes the relatively soft thin lead and brass plate on the wire. For these reasons the wire tensions developed by the take-up spool drives must be controlled within narrow limits.

The power required to drive a take-up spool is practically constant from an empty to a full spool, but the rotary speed of the spool must decrease as the spool fills up, while the driving torque must increase to compensate for the increase in winding radius. The take-up spools are therefore individually driven with compound-wound dc motors which automatically slow down as the spool fills up, meanwhile holding wire tensions between 15 and 20 pounds from start to finish of a spool.

All the plated wire produced from a 450-pound core wire supply is taken up on one spool to eliminate intermediate wire cuts, and to produce

Fig. 4 — Finished wire, after a series of cleaning and plating operations in the electroforming process, is wound onto take-up reels for final inspection and shipment to the Wire Shop.

the longest lengths of plated wire that can be made from a single reel of core wire. This means that for each core wire reel that goes onto the pay off stands, one spool of plated wire comes off at the take ups. This practice reduces scrap operating losses and spool handling, and simplifies the keeping of production records. The take-up spools, which nominally hold 600 pounds of plated wire, were made large enough to take 750 pounds. This allows steel wire suppliers up to 50 pounds overrun above 450 pounds of core-wire per spool.

The spools are made with large arbor-holes which are slightly countersunk to provide seating surfaces for engaging cone plates which hold the spool in the take-up stand. The cone plates clamp the spool between them under the pressure of a direct-acting compressed air cylinder closure, which permits quick loading and ejection of the spools and greatly reduces the time required to make spool changes thus keeping scrap to a minimum. Driven pinch rolls are provided at each take-up stand to draw the wire from the take-up capstan while a spool change is being made. The pinch rolls do not contact the wire while it is being wound onto a spool. Operating linkages are provided whereby the pinch rolls are applied to engage the wire at the instant the take-up spool is stopped. In this way there is no pause and no interruption of the wire's motion from the take-up capstan. Wire passing through the pinch rolls is slightly flattened, so it must be scrapped. Spool changes can be made quickly enough so that no more than 10 feet of wire in 125,000 feet have to be scrapped from this cause.

The wires are laid evenly on the spools with a gang-distributor driven by a separate motor. The spool traverse is wide, the wire lay is close, and the distributor travel can be accurately set, both at the distributor traversing screw and at the individual take-up position, so that the wire will be distributed on the spools without camber or end pile-up. Every precaution is taken to insure good wire distribution on the take-up spools, because the wire is subsequently taken off them at high speed at the insulators where wire breaks resulting from faulty wire distribution cannot be tolerated.

PLATING MACHINE

The plating machine frame is a simple structure built up of regular structural steel sections and lined with sheet steel. The cross section of the machine resembles the letter "H" with the cross bar set low. The tops of the "H" are joined to lengthwise channels, which form a continuous rail. The bottoms of the "H" are welded to heavy longitudinal channels which transmit the weight of the machine through rollers to a

pair of heavy lengthwise "I" beams which form a part of the building structure. Supported within this framework is the "U" shape trough of stainless steel or low carbon sheet steel covered with Koroseal lining if required by the electrolyte utilized. A step is formed in the bottom corners of the 'U" to support the plating cells leaving a trough-shaped channel in the center for the return of the electrolyte. The header from which the electrolyte is supplied to the individual plating cells is located between the legs of the "H," flanked on one side by the positive electrical bus and on the other by the negative bus. Partitions are provided as required in the length of the trough to separate sections in which different electrolytes are confined. The entire machine is sloped towards the central portion of the building so that the effluent electrolyte is directed to the low portion where a downspout to the solution storage tank on the floor below is provided.

The actual plating operations are carried out in a series of cells which are supported on the steps in the return trough by insulating blocks (Fig. 5). All cells are of the same basic design. A typical cell consists of a "U" shaped body of formed and welded sheet steel which may be low carbon steel, stainless steel or low carbon steel Koroseal lined and covered, depending on the particular electrolyte involved. Studs are mounted in both ends of the body for fastening the weir plates. These are of molded hard rubber and provided with twenty-five equally spaced slots on 1-½" centers to pass the wires. The weir plates on the two ends of the cell body differ in thickness, the thick weir containing an interior manifold which serves to distribute electrolyte uniformly across the cell and which is connected to the electrolyte supply pipe by a flexible rubber ell. Molded rubber spill catchers are bolted to the outside of the weir plates to collect the electrolyte discharged from the weir slots and direct it through a rubber tube into the return trough with a minimum of splash.

In the case of unlined cells, the cell body serves as anode or cathode as the operation may require and the electrical connection from the bus bar is made directly to a tap on the cell body. For the lined cells, an anode plate of a suitable metal is provided in the bottom of the cell and covered with anode material in the form of cast shot. In this arrangement, all the electrolytic corrosion takes place on the shot bed, leaving the lead-in plate undisturbed.

The thick, or feed weir, is placed on the low end of the cell to take advantage of friction loss in the long weir slots to reduce the discharge of electrolyte from the cell. Maple wedges coated with vinyl paint placed between the cell bodies and the trough sides allow easy and accurate

Fig. 5 — Typical cell of the many in each of the two 600-ft. long electroforming machines shows how the twenty-five channels of wire pass through a plating solution and are propelled and fed electric current by rolls like that seen in the foreground. An operator, wearing his protecting safety gear, checks over the operation.

alignment of the weir plates with the wires and maintain the cells rigidly positioned.

The electrical circuit for the plating current is completed through the contact rolls which position and make contact with the wires between plating cells. The rolls are heavy-walled tubes carried on axial shafts by internal ball bearings and insulated from the machine frame. The materials of construction are copper, steel, stainless steel, or monel metal, depending on the electrolyte involved. The ends of the tubes project through the trough walls and the shafts are carried on external brackets which bolt to the upper longitudinal frame channels. One of the brackets is cast iron and the tube on this end is furnished with an insulated sprocket for the driving chain. The other bracket is a copper casting, insulated from the machine frame and carrying brush holders for copper-graphite brushes which contact the opposite end of the tube. The plating

current is carried from the copper casting by a flexible connection to the bus bar. The surface of the tube is provided with shallow grooves on 1-½″ centers to position the wires and the whole contact roll assembly consisting of tube, bearings and shaft can be shifted laterally to bring a new set of grooves into play when wear dictates.

Pilot plant experience had shown that electrolyte will be carried by the wires to the contact rolls and will spread out over their surface, eventually reaching the bearings and the brush contacting surfaces. Some type of seal had to be provided where the roll passed through the wall of the trough. Various types of commercial seals were tried, but all left much to be desired. The seal finally developed for the application is in two parts: a molded Neoprene double slinger ring on the roll, operating in a molded Neoprene housing inserted in the trough wall. The slinger ring successfully prevents the passage of electrolyte while the housing prevents splash from carrying past. This seal has the important further advantage that there is no contact between the fixed and moving parts so that there is no friction loss and no wear. Also, it is a simple molded rubber part which slips into place and requires no fastening.

The wires, in their travel through the plating machine, are acted upon by nine different electrolytes. An appreciable amount of electrolyte is carried with them and if means were not provided to remove the envelope of solution, the succeeding baths would be quickly contaminated, and in some cases dangerous gases would be generated. In general, the transition section between dissimilar electrolytes is made up of an air wiper, a water wash and a steam wiper, in order of wire travel. The wiping element at each wire is the convergent blast of steam or air from three small nozzles. Twenty-five sets of these nozzles, one set for each wire channel, are mounted in a manifold. In the case of an air wiper, the spent air and droplets of electrolyte wiped from the wire are directed into an eliminator where the droplets are caused to separate from the air stream by impinging on the metal baffle plates. The steam wiper is of similar construction except that a water-cooled condenser is substituted for the eliminator. The cooling water for the condenser is discharged into a typical cell, mounted between the two wipers where it washes the wire and discharges to waste.

While these washing facilities may appear somewhat elaborate, they are justified on the basis of reliability and safety. The failure of any one of the three services, air, water and steam, will not cause appreciable contamination before repairs can be made.

At the copper cyanide, brass cyanide and acid copper plating sections, the wipers are preceded by dragout recovery units. A dragout recovery

unit consists of a cell and a small, individual reservoir with a small pump which circulates the liquid in the reservoir through the cell, the overflow returning to the reservoir. Makeup water to replace that lost by evaporation in the associated plating section is added to the reservoir, serving to continuously dilute the electrolyte washed from the wire. The reservoir operates at constant level, the excess of dilute electrolyte passing on as makeup. The dragout recovery units act as an additional safeguard to limit the loss of valuable plating solution and to minimize the contamination of wash water going to sewer.

Last in the design of the machine are the precautions taken to protect against stray currents and to provide for expansion and contraction. Protection against stray currents is an important consideration in any equipment employing highly conductive liquids and heavy currents. All plating cells are insulated from the machine frame by their supporting blocks. Both positive and negative plating circuit buses are insulated. All electrolyte pipe lines contain neoprene flexible joints which serve both to sectionalize them electrically and to provide for expansion and contraction. Contact rolls are insulated at their mountings. These are the principal precautions taken.

The expansion and contraction problem was rather complex. The three trough sections of each machine are continuous units, the shortest 77 feet, the longest 300 feet in length. The plating cells in the trough are supplied with current and electrolyte from a number of different locations in the building and the building itself is provided with a single expansion joint in the center. To allow for relative motion between machine and building, the machine sections are mounted on rollers. Since these sections are required to operate at various temperatures, from room conditions to 195°F, and are required to be supplied at frequent intervals with current and electrolyte, all electrical connections to bus bars are made with flexible joints and electrolyte is supplied to each plating cell through a special flexible molded ell.

Each machine section is anchored to the building steel to prevent creep. An analysis was made of the several movements to be expected under various operating conditions and ambient temperatures and the anchor point was selected for each section so that the relative motions are minimized.

PLATING OPERATIONS

From the chemical point of view, the electroforming process consists of a series of unit processes in tandem, to clean the steel core wire and to successively deposit the several metallic coatings required to make

the completed conductor. In tbe course of the complete travel thru tbe machine the wire receives thirty-two separate treatments in nine different chemical solutions.

The first solution that the wire enters is the alkali cleaner whicb removes oil, drawing compound and dirt. The heated bath contains an alkaline solution with a small quantity of a wetting agent. This section of the machine contains eight stainless steel cells alternated witb seven stainless steel contact rolls mounted in a stainless steel trough. The wire is anodic with the body of the cells acting as the cathode. A current density of 100 amps./sq. ft. is applied to the wires causing a heavy ebullition of gas which materially helps the cleaning operation. The alkali cleaner section is followed by a steam wiper.

Next the wire passes into a sulfuric acid pickle section wbere scale, rust and occlusions are removed and a slight etch is imparted to the surface of the steel to promote adhesion with the subsequent copper deposit. A small quantity of an inhibitor is added to prevent the dissolving of an excess amount of iron which would result in a heavy carbon smut on the surface of the conductur. There are six cells and three monel metal contact rolls. Following the pickle is an air wiper, a water wash cell and a steam wiper. This completes the cleaning and preparation of the wire surface prior to the first plating operation. The tank and cells in the sulfuric acid are constructed of Koroseal lined mild steel.

The initial coating is a thin layer of copper from a copper cyanide solution termed a "cyanide flash" and is designed to give a smooth deposit. There are five plating cells and four contact rolls of low carbon steel and the machine trough is likewise of low carbon steel. Tbe wire is cathodic and the copper is deposited at a relatively low current density.

Following the copper cyanide flash the wire passes directly to tbe copper cyanide plate solution where a copper coating of not less tban 0.0001" thickness is applied in a bath designed to operate at a high current density and, therefore, at a higher rate of deposition than is obtained in the flash bath. Seventeen plating cells alternated with sixteen contact rolls are needed to deposit the required thickness at the operating current density. Cells, rolls and troughs are made of low carbon steel, and copper shot resting directly on the steel cell bottoms forms the anode surface. The cyanide plate section is followed by a dragout recovery unit, a water wash cell and a steam wiper. This completes the preparation leg of the machine.

When the wire leaves the preparation leg, it passes through a turning section (Fig. 6) which reverses the direction of travel prior to entering the acid copper plate leg where the bulk of the copper is deposited.

Fig. 6 — Turning section of the machine where the twenty-five channels of wire, after having been cleaned and partially plated in the tanks on the left, reverse their direction and travel the full length of the building, receiving added copper coating in the series of plating cells.

The production plating machine has 58 plating cells alternating with 57 copper contact rolls. The plating solution is very corrosive so that all surfaces of containers are covered with Koroseal. Copper plates in the bottoms of the cells distribute current to a bed of copper shot which forms the active anode surface.

A relatively large number of cells is required because of the magnitudes of the total plating currents involved. Faraday's Law shows that several thousand amperes are required to deposit copper at the rate of 0.001″ per minute.

Instantaneous fusion of a steel wire 0.033″ in diameter would result if this current were forced through it at one time. The repeated passage of smaller currents which will not overheat the wire will, however, deposit the same amount of copper. The design of a plating section thus takes the form of a number of plating cells separated by contact rolls.

The contact rolls are designed to have a wall thickness of copper adequate to prevent more than a negligible voltage drop between the two outside wires in the machine. This insures that the same voltage is ap-

plied to all wires across the machine and permits a design in which the current collecting brushes are always located on the same side of the machine.

When the wires leave acid copper plate cell No. 58, the full deposit of copper has been applied. They pass into a dragout recovery cell where they are washed by the makeup water, through an air wiper, and a water wash cell before entering the heat treat section. The heat treatment has two functions: First is to change the grain structure of the deposited copper to an annealed form having small random cyrstals free of strain. Second is to strain relieve the hard drawn steel core wire sufficiently to increase its elongation to between 3 and 7 per cent. This is accomplished by passing current through each wire to heat it to the necessary temperature. The heat treated wire passes through a water wash cell which serves as a quench and through a steam wiper which dries it in preparation for entering another turning section where it again changes direction 180° to enter the finish leg of the machine.

The first solution that the wire enters at the finish leg is hydrofluosilicic acid which serves to remove any oxide which may have formed in the heat treatment. This cleaning operation is performed in a single koroseal covered cell.

Four koroseal covered cells, three copper contact rolls and a koroseal lined section of trough make up the lead plate section. The electrolyte is lead fluosilicate. Lead sheets in the bottom of the cells are covered with lead shot to form the active anode surface.

The brass plating section applies the final deposit to the wire. Its function is to provide a coating which will unite chemically with the insulating compound, giving good adhesion so that the load from the drop wire clamps used to support the wire in service will not cause the insulation to slip on the conductors. The composition of the deposited brass is controlled between very close limits to obtain the desired adhesion between conductor and insulating compound. The electrolyte contains copper and zinc cyanide. There are four steel plating cells, three steel contact rolls and a low carbon steel trough in the brass plate section. The anode material is a mixture of copper and brass punchings which rest directly on the steel cell bottoms. The finished wire is then wound onto 660-pound reels.

ELECTRICAL POWER

Electrical power is purchased from the local utility company at 13.2 kv and brought into the building by a pair of three-conductor, 300,000 circular mil, 15,000-volt, lead-covered cables running in underground

ducts. These are terminated in two 1500-kva metal-clad substations which consist of high-voltage switching units, transforming units, and low-voltage feeder units. Each unit substation has the self-cooled rating given in Table I.

On the incoming line side of each substation are two load interrupter disconnecting switches so that the building may be supplied by either of the two incoming high-voltage cables. The high-voltage switches feed the power into the two transformers, each of which is rated at 1500 kva, three-phase, 60-cycles, 55°C rise, and is self-cooled, filled with non-inflammable liquid. For a short time interval, with proper switching, either of these transformers can supply the total building load if fan cooling is provided.

The 480-volt power from each transformer is then fed into its respective low-voltage switchgear for distribution to various parts of the building. Lighting, heating and ventilation services are provided totally from one substation by way of a disconnecting bus tie switch which automatically throws over to the other substation in case of failure of one.

Table I

Capacity (55°C.)	1500 kva
Normal voltage	13200/480-277 delta-wye volts
Frequency	60 cycles
Phases	Three
Circuits:	
Three-wire incoming, 12300 volts	Two
East unit, four-wire, outgoing 480/277	Six
West Unit, four-wire, outgoing 489/277	Five

Other than the lighting, heating, ventilation and some plant services, each substation is designed to supply power for the operation of one machine.

From each substation one low-voltage ac feeder supplies on its machine a number of rectifiers which transform and rectify the 480-volt, three-phase, ac power to dc power at a low voltage. From this feeder is supplied all of the "auxiliary" plating power for that machine: alkali cleaner, acid pickle, cyanide copper flash and plate, electrocleaner, lead plate and brass plate. In addition the dc power for establishing the field in the magnetic capstan is supplied from a rectifier on this feeder at 55 volts.

Another low-voltage ac feeder from each substation feeds through an induction voltage regulator which in turn feeds sixteen rectifiers of one machine. From these rectifiers is taken the dc plating power for the acid copper plate section of the machine. The function of the induction voltage

regulator is to automatically control the dc plating current in the acid copper plate section through a control system which continuously measures the electrical resistance of the product and signals the need for variation in power in accordance with the variation in resistance.

All of the rectifiers associated with one machine (Fig. 7), including the "auxiliary" units and those on the regulated feeder, are located in the outer mezzanine bay nearby that machine. The two regulators, although each is associated with a different machine, are both located in the substation room on the south side of the building.

The induction voltage regulators are basically standard regulators of the type used in lighting service but modified slightly by the addition of a control slidewire for electrically indicating the position of the rotor. Each unit is three-phase, self-cooled by non-inflammable liquid, rated at

Fig. 7 — Electrical heart of the electroforming process are these rectifiers and controls where alternating current is converted to direct current.

480 volts ac and having at least 105-kva capacity according to NEMA standards. Each regulator is able to buck or boost line voltage by 20 per cent at maximum rectifier load.

The rectifiers used for converting three-pbase, 60-cycle, 480-volt ac power to low voltage dc are all of the copper-oxide "dry-disc" type. A detailed investigation of various sources of dc power was made before this type of converting equipment was purchased. Because of the similarity between the continuous copper plating of wire and the continuous tin-plating of sheet steel, a tour of several steel plants which plated strip steel in a continuous process was made. Here were observed some of the best and some of the poorer installations of electrical converting equipment, including motor-generator sets, copper-oxide rectifiers and selenium rectifiers. This survey terminated in a decision to use totally enclosed, air cooled copper-oxide rectifiers, in which the enclosed air is recirculated past air-to-water heat exchangers for cooling purposes. This decision was based on a desire for low maintenance costs, efficiency, compactness of installation and flexibility. Choice of copper oxide over selenium rested on the fact that copper oxide rectifiers are less costly and better suited for low voltage output (less than 6 volts).

The actual design of the rectifiers was arrived at after a series of conferences between Western's engineers and tbose of the manufacturers. Accessibility of all parts for inspection and maintenance purposes, adequate protection of components through control circuits, limited occupancy of floor space and low cost were design criteria. These features are nicely combined in the final design and the manufacturer standardized the rectifier for sale to other purchasers.

Each rectifier is of the completely enclosed, air recirculating type. It is equipped with its own heat exchanger and is gasketed to minimize air leakage. The air-to-water heat exchanger is of a type expecially designed for use with well water containing some fine sand. It features ease of cleaning and is a type suitable to these conditions. The fins and tubes are of copper and water connections are external to the rectifier housing.

All other components are readily accessible through gasketed doors in the housing. One or two fans, as required, circulate the air within the rectifier housing to transfer the heat generated in the rectifier cells and in the transformers to the water cooled heat exchanger. As protection both to equipment and to personnel, a rectifier can be automatically tripped off the line for any of the following reasons: Electrical overload and short circuit, dc over-voltage, failure of air circulation, overload of fan motor, water failure, momentary power interruption, over-temperature of the air, and by opening any of the doors on the rectifier.

Control of the output of the entire bank of rectifiers of the acid copper plate section is accomplished through the associated induction voltage regulator. Individual adjustment of load and compensation for aging of the rectifier stacks has been provided for hy bringing out to terminal boards within the housing a numher of leads from the primary windings of the rectifier transformers. For a given feeding voltage, the output of each rectifier can be adjusted over a considerable range by the positioning of jumpers at the terminal boards. Except for aging compensation, this adjustment, once made, need not he made again. Control of the output of the "auxiliary" rectifiers is accomplished by tap-switching, under load, between taps brought out from open-delta autotransformers on the primary side of the rectifier transformers.

The capacity of the bank of the sixteen rectifiers feeding the acid copper plate section of each machine is larger than is actually required to produce the wire. With this additional capacity distributed among the rectifiers, it is possihle to continue plating operations in case of failure of one rectifier. The automatic control system will increase the output of the remaining fifteen units immediately after the one has dropped off the line.

The bay in which all rectifiers are located is separated from the operating bay by a plaster partition which serves the purpose of forcing the incoming fresh air flow past the rectifiers protecting them from any corrosive atmosphere which might be present in the operating bay. The rectifiers are placed against the wall and their bus terminals extend through small apertures into the operating bay. Because the operating bay floor level is about two feet higher than that of the rectifier bay, the rectifier terminals emerge from the plaster partition below the floor elevation of the machine. This permits the running of the busbars out to the machine hy passing them under the operators' walkways.

These feeder hushars from the rectifiers terminate beneath the section of the machine which they are to feed. Flexible laminated connectors join the feeder huses with the huses running longitudinally under the machine: from the longitudinal huses additional flexible connectors carry the current up to the rigid terminals leading into the plating cells or up to the copper castings supporting the brushes and contact rolls.

The dc circuit, both inside and outside the rectifiers, has been completely insulated from ground excepting that grounding caused by electrical contact with the wire itself. Stray currents are thereby minimized and kept out of pipe lines or building steel.

All of the busbars used on the machine are of the square drawn copper tubing type. Aluminum was considered but rejected because of the seri-

ous danger of electrolytic corrosion at the joints (which necessarily had to be made to copper) from the warm, moist, corrosive atmosphere. The square copper tubing is ventilated by holes drilled in the upper and lower faces to give it comparatively high current carrying capacity with low temperature rise. The fact that the bus is in the form of tubing gives it an inherently high mechanical strength; the supports for the tubing, therefore, could be spaced much farther apart than for ordinary bus. All tubing bus joints are of the compression type made up by the use of standard clamps rather than by brazing or bolting. All of the tubing was purchased cut to size and coded. During installation, the preparation of the joining surfaces was carried out on benches in the area. Such planning resulted in an exceptionally easy and rapid installation.

A complete picture of the electrical operation of a given machine is provided to the operator through a control console located in the operating bay of the mezzanine (Fig. 8). On the control console are located the tapswitches for adjusting the output of the "auxiliary" rectifiers, an ammeter and a voltmeter for each rectifier (a total of forty-six such meters per machine), a meter which indicates wire speed, switches for

Fig. 8 — Control console for the entire process is readily available when necessary.

the ventilating roof fans, a switch for removing the magnetic field from the supply-end capstan, a selector switch for selecting the speed of wire passage through the machine, and seven push-button stations which give the operator individual control over various elements of the machine. The push buttons energize relays mounted in a bank within the control console and thus permit a large degree of interlocking. The interlocking is designed to prevent accidents from occurring in the process. For example, the operator cannot permit the pickling acid to flow over the wire while the wire is stationary; otherwise the acid would dissolve the wire in a short time. Time delay relays also are used to advantage. They insure, for example, that the full length of moving steel core wire has its flash coating of cyanide copper prior to the rise of the acid copper plate solution into the cells and around the wires which, without the copper envelope, would be eaten through in a short time.

The overall machine control system has been broken down into two parts because of the two-floor design. From his console, the second floor operator controls only those portions of the process which are visible to him on the second floor. He can, for example, permit solution to flow into the plating cells by electrically opening the valves in the circulating system. Actual control of the first-floor pumps which move the solution, however, is in the hands of the first-floor operator who has a control panel strategically located near each storage tank and pumping station. Here he can operate filters, pumps and level control systems.

WIRE RESISTANCE CONTROL

There has been provided for each machine in the electroforming plant a control system which automatically adjusts the dc plating current in the acid copper plate section to that value which, under all normal operating conditions, will produce a wire meeting the electrical resistance specification for the product.

Control is necessary because of the number of variable factors which, if uncontrolled, would interfere with the proper flow of plating current and, therefore, with the amount of copper deposited. These variable factors can occur in the physical and chemical properties of the raw materials entering the process, in the plant services feeding the process, and in the process itself. Some of the more important variables are as follows:

1. Incoming electrical line voltage fluctuations.
2. Failure of one of the sixteen rectifiers feeding the acid copper plate section.

3. Changes in the temperature or in the concentration of the electrolyte.

4. Changes in the distance between the anode bed and the wire because of the wasting away of the anode bed during plating operations.

5. Wire speed changes (by removal of the magnetic field from the supply-end capstan).

6. Operation of the machine at less than its capacity number of channels.

Control is justified by the savings in copper which accrue, by the relieving of the operating personnel of tasks which could become tedious, and by the resulting production of an exceptionally uniform product. In view of the size tolerances available on steel wire, it was decided that the most practicable approved way was to manufacture to uniform conductivity and to ignore wire size within reasonable limits.

Two systems produce the overall control function. A primary system senses the total value of the dc current in the acid copper plate section by means of a current transformer located in one phase of the common ac feeder servicing all sixteen rectifiers. Changes in that current are immediately detected and compensated for by adjustment of an induction voltage regulator located at the head of the feeder. This system therefore maintains the dc plating current essentially constant in value and corrects for such fluctuations as are listed from 1 to 4 above before they can seriously affect the product.

Changes in certain other variables, as exemplified by 5 and 6 of the above list, require that a new value of total current be established and maintained constant by the primary system. Otherwise the maintaining of the previous value of total plating current would result in a change in the resistance of the product. Such variables are cared for in a secondary control system which uses the resistance of one of the finished wires as the control parameter. The secondary system automatically positions the control point of the primary system, depending on the value of electrical resistance of the pilot wire which is measured continuously.

In addition to control equipment each machine has an inspection device which automatically measures the resistance of each of the twenty-five wires and records the values on a chart. A cycle of all twenty-five wires is completed each hour.

Both the control and inspection resistance measuring equipments use Kelvin Bridge circuits and measure approximately five feet of wire at one time. Continuous contact with the wire being measured is made through rotating sheaves and brushes. This avoids any scraping of the soft lead and brass surfaces of the product.

The inspection wire contacting device automatically moves from wire to wire across the machine, sampling the resistance of each wire for about fifteen seconds. The chart provides the observer with a complete picture of the behavior of the plating operations at a glance and enables the operator to properly select the controlling pilot wire in such manner that minimum energy and copper are expended. The control wire contacting device is manually set in position against one wire until conditions require selection of a new pilot wire.

Both contacting devices are located in the position just preceding the take-up capstan from which the wire moves down to the first floor to be taken up on reels. To avoid the by-passing of the bridge current through ground and the building steel, each channel has been completely insulated from ground and from other channels between the contacting devices and the end of the wire on the take-up spool. The take-up capstan, all sheaves, guide tubes, rollers, and the take-up stands themselves have been designed to provide the required insulation.

Aside from presenting to the operating personnel a complete chart showing the values of the electrical resistance for each channel, the sensitive resistance measuring equipment also gives indication of process difficulties long before they are evident from any other source. For example, an increase of organic contamination above certain concentrations in the acid type plating bath will produce wide variations in the structure and, hence, in the electrical resistance of the copper deposit. These fluctuations can occur in very short sections of the product. While the average value of the resistance may remain constant for long sections of the product, the resistance charts provided by the control and inspection equipment will record the individual wide fluctuations and thereby provide experienced operating personnel with a positive indication of imminent serious trouble.

SOLUTION HANDLING

In this plant, all unit processes are similar if not identical in arrangement and operation.

A typical handling system consists of a storage reservoir, mixing and filter station, circulating pumps, heat exchanger, solution supply, and return piping between storage tank and processing area, and a solution temperature and level control. (Fig. 9.) The chemicals of which the electrolyte is composed are placed in the mix tank and agitated. This mixture is then transferred through the filter into the storage tank. The filtered solution in the storage tank is first circulated through the heat exchanger and finally delivered to the processing area on the mezzanine

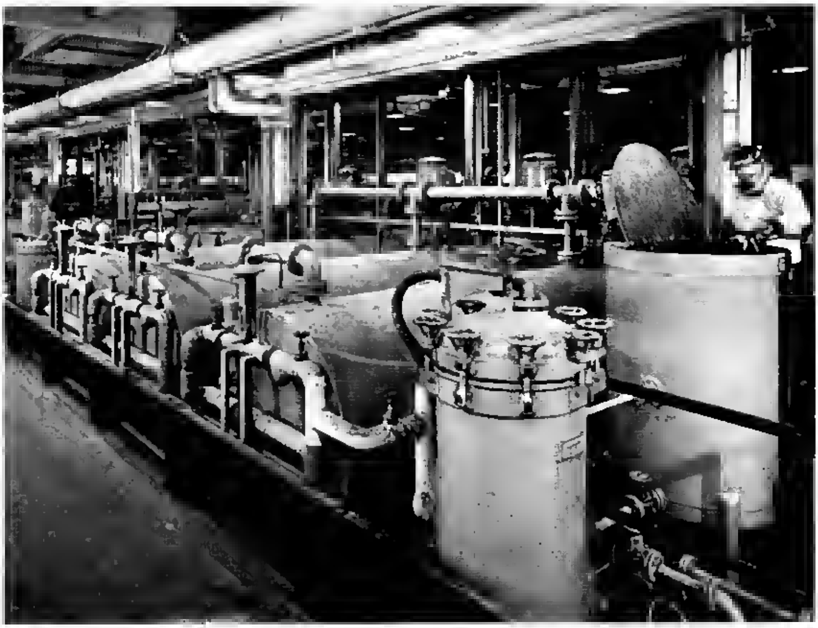

Fig. 9 — Solutions for the plating operations are stored in this battery of tanks. Full safety equipment is worn by the operator as he performs the job of tank-filling.

floor. It returns by gravity to the storage reservoir and the cycle is repeated.

The storage reservoirs are cylindrical horizontally mounted steel tanks. Those containing acid solutions are Koroseal lined, and many are covered externally with thermal insulation. All tanks have the same inside diameter, but vary in length depending on storage requirements for each electrolyte. Since the electrolyte used in similar unit processes of the two machines is the same, provision has been made for complete interchangeability of solution between the storage tanks of the two machines.

The purpose of the filtering operation is to permit the continuous removal of suspended solids and foreign material in the process solutions. The mixing and filter station provided for this purpose is an assembly of components all of which are mounted on a common base or platform. The basic assembly consists of a closed pressure type alluvial-leaf filter, centrifugal pump, mixing tank with agitator, various valves for directing and controlling the quantity of solution, water and air used in the filter operation, and a discharge to sewer for cleaning. Within the pressure tank a series of double faced screen assemblies or leaves comprise the

filtering elements which hold back the undesirable solids and discharge a clear product into the common filtrate manifold on which they are mounted. There are eight leaves in each pressure tank providing sixty square feet of filter area. The filter cycle is begun by filling the mix tank with unfiltered solution or electrolyte from the storage tank. Sufficient filteraid for precoat is rapidly mixed in by agitator. This mixture is forced through the filter leaving a deposit or coat of filteraid on the intake surface of the leaves. The purpose of the coating is to provide a filter medium which is dense enough to prevent the passage of suspended solids in the solution and yet is easily removed and replaced. The appearance of the liquid on returning to the mix tank gives an indication when an adequate precoat has been deposited on the leaves. Once the coat has been applied, the filter is put on the line and clear filtrate is discharged to the storage tank. The filtration stage terminates when the filter tank pressure approaches a maximum operating value, at which time the leaves are washed, a new coat is applied, and the cycle is repeated.

The storage reservoir is fitted with one or more heavy duty vertical sump type pumps to transfer the electrolyte in the processing area. All pump parts in contact with chemical solutions are constructed of either cast iron or a stainless steel alloy known in the industry as FA-20. All pumps are fitted with graphitar bearings. Each pump is connected directly to its electric motor and the entire assembly may be quickly removed from the storage tank.

All piping associated with solution handling is either steel or saran-lined steel. The Saran-lined pipe has flanged type joints and the unlined steel pipe has welded joints except where disassembly is provided for and here welded-on flanges with neoprene gaskets are installed. Flexible neoprene joints are provided in the solution riser and return pipe to insulate the plating machine from the circulating pumps. To control solution flow to the processing area, air operated diaphragm valves have been installed.

The two-pass heat exchanger selected for the process consists of a steel shell, but all parts in contact with corrosive solutions, including the tube bundle, are constructed of a chemically inert carbonaceous material. The heat transfer rate of this graphite base material is the highest of all non-metals and is higher than that of most metals. For example, the thermal conductivity of 18-8 stainless steel is approximately one-fifth that of the graphite base material.

Operating temperatures for all solutions are specified and equipment to control these temperatures has been provided. The temperature of each solution is measured with bulb type expansion thermometer. The

temperature is recorded by an instrument attached to the outer trough of each process on the mezzanine floor. In addition to recording temperatures, the instrument also operates a spring loaded valve, by air pressure, in the heat exchanger piping. The correct operating temperature can be chosen by setting the manually operated pointer on the recording chart.

Automatic, electrically operated, liquid level control devices have been provided for each solution. These controls are provided for the following reasons:

1. The evaporation of water from the solutions used in the process is of such magnitude that some means of maintaining solutions within their proper concentration range is necessary.

2. The solution level in the storage tank must not reach a specified lower limit, or the circulating pump suction head will fall below the minimum operating value.

3. When the electroforming machine is in operation, the total solution volume in any unit process is composed of the portion in storage and the portion in circulation. If the portion of solution in the storage tank exceeds a known value, the remaining volume of storage space will be insufficient to accommodate the circulating portion of solution which returns to storage when the machine is shut down.

The liquid level control device consists of four electrodes which dip into the contained solution. The four electrodes are arranged so that as the level varies, the solution closes different electric circuits. During normal operation at proper level, the electrical connection between the low electrode and a common electrode holds the solenoid operated water valve closed. When the level falls about ½″ below the prescribed level, the circuit opens and releases the solenoid water valve to the dragout recovery cell or the valve in the water line leading to the filling nozzle in the storage tank. When solution again rises to the prescribed operating level, another tripping circuit is activated which causes the water valves to close.

In order to show whether or not the level controls are operating satisfactorily, a red and a green light are mounted above and in line with each storage tank. When the green light is on, the levels are proper. The red light is a signal that the level is increasing beyond the point at which the tripping circuit should have been activated. In this case, the water valve is immediately turned off. When both lights are on, the solution level in the reservoir is low and make-up water is added automatically.

Due to the chemical action of fluoboric acid on the copper anode material in the acid copper plating bath, the copper concentration of the solution rises during operation of the electroforming machine. In order

to hold the concentration within the established operating range, copper removal equipment was developed.

The equipment consists of two Koroseal lined tanks installed in a concrete pit and fitted with graphite anodes and sheet copper cathodes. When the copper concentration of this solution exceeds the maximum operating value, the pump associated with the copper removal unit automatically cuts into the acid copper plate equalizer line and transfers solution to the removal unit. The excess copper in solution is electrolytically deposited onto copper cathodes, and the restored solution is returned by gravity to the equalizer line.

RAW MATERIALS HANDLING

Except for the anode material (shot), all materials handling is confined to the main floor. In this way the plating deck operators are fully relieved of all materials handling chores, other than the one job of replenishing anodes in the cells, and this job is purposely delegated to them because anode maintenance is a critical part of the plating deck operator's responsibility for product quality. All heavy, bulky units are handled on the main floor so that none of the untidiness and confusion always attending the opening of containers, truck movement, and receiving and shipping operations are present on the plating deck to interfere with the prime job done in that area.

All chemicals to be used in the various cleaning and plating solutions are stored along the north wall of the building, each in the area nearest the preparation and mixing equipment in which it will ultimately be used. Wherever chemicals are stored close to one another, which, if accidentally mixed, might create hazards, solid barrier walls are provided to keep them separate. Chemicals are stored in their shipping containers, all of which are fully identified as to contents and adequately marked with any warning labels which might be required. Chemicals, at the receiving dock at one end of the building, are removed from the motor truck, placed on wood pallets, and transported by electric truck to the storage area. The use of pallets for handling and storing the chemicals reduces the total electric truck haul-time and protects the containers from mechanical abuse while in storage. The wood pallets also permit flushing of the floors without soaking the containers, especially those of paper or wood. Facilities are provided for flushing out the emptied container as as well as for washing down the floors after accidental spillage or breakage.

Wire is stored along the south wall of the building physically well

isolated from the chemical storage, handling and mixing operations along the north wall. This minimizes exposing the wires to the splash or vapors from the chemicals which would damage the wire. Core wire is the bulkiest and one of the heaviest items handled. It is stored in an area near both the core wire pay-off stands and the receiving dock, to shorten the truck-hauls and enable the pay-off stand operator to obtain his core wire supply direct from storage without leaving the operating area. The core wire supply reels are narrow and of large diameter so they can readily be handled upright, and rolled along on their head rims. From the upright position, the reels are picked up with a rotatable grapple on a monorail hoist, turned 90 degrees, and placed head down on a waiting transfer car to be moved to the supply or pay-off stands. The transfer car operates on steel rails flush with the floor so that the car can be spotted close alongside the pay-off stands, without danger of being bumped into them (Fig. 1) The bed of the transfer car as well as the beds of the pay-off stands are built up of gravity roller conveyor sections and in loading position both are at the same height. The reel is easily pushed off the car and onto any pay-off stand. Emptied core wire reels are removed with the same equipment and accumulated in the storage area for return to the supplier.

ANODES AND ANODE HANDLING

Soluble anodes for the plating cells are supplied in the form of random-cast shot or pellets and punchings varying in diameter from about $\frac{1}{4}''$ down to $\frac{1}{32}''$, the percentage of fines being limited by raw material specifications to control the rate of dissolution in the plating electrolytes and to limit the formation of anode muds or sludge. The copper shot is cast from commercial wire-bar copper. The lead shot is made from commercially pure virgin lead, and the brass punchings are obtained from lead-free brass scrap. The brass anode usually contains too much zinc, so the brass bath composition is corrected by adding pure copper shot in with the brass, the proportions being determined by plating bath and plate composition analysis. The shot is laid evenly in a bed about 1″ thick over a relatively thin plate electrode covering the entire bottom of the plating cell. Plating potential is supplied to the soluble anode bed through the electrode.

In the cyanide brass and cyanide copper plating cells the anode material is spread directly on the steel bottoms of the cells, steel not being soluble to any consequential extent in the cyanides. Lead electrodes are used in the lead plating cells. The lead and brass anode materials are

used in such small quantities that they are replenished by hand. Copper, however, is plated out of each machine at the rate of 900 pounds per eight-hour shift. Copper shot added to replenish this plate-out from the cells must be spread out evenly over a cell area of more than 500 sq.ft. extending 280 ft. along the machine. When this is done, the average depth of the material added is less than $\frac{1}{10}''$. As a quality control on the copper plate, the anode-to-cathode spacing in the cells (copper shot layer-to-wire spacing) is not permitted to vary from the specified spacing by more that 25 per cent at any spot on the cell surface and the average must not exceed 15 per cent. Shot must be added at least once every eight hours to meet this requirement, and the addition must obviously be made while the wires are running. It would be impracticable to do this job manually in any reasonable time and with any assurance that the quality of the electroformed copper deposit would not be impaired during the addition.

Copper shot is, therefore, added to the cells with a mechanical distributor which automatically sprinkles the shot into the cells uniformly while the machine is running. It is essentially a hopper mounted on a motor driven carriage which travels on the two upper rails of the acid leg of the machine, the bottom of the hopper being fitted with a rubber surfaced feeder roll and a stripper comb which releases from the hopper a controlled amount of material. The feeder roll is also motor driven and timed relative to the travel speed of the carriage. Both carriage and feeder roll are operated from rubber grips so that the machine operator may stop the distributor wherever he wishes or by-pass any cell if he so desires. To prevent the spillage of shot on the contact rolls between the cells, block-out cams are placed on one rail to operate a cut-out switch which stops the feeder roll while the distributor passes over the contact roll space between cells. The speed of the feeder roll can be varied, and the height of the stripper comb can be changed to vary the amount of shot released per foot of distributor travel. A feed run of the distributor requires an operator's attendance and takes about twelve minutes to discharge shot to the entire acid-copper plating line. The distributor returns to its starting point automatically when the feed-run has been completed. The feeder roll is inoperative while the distributor is returning. Power is supplied to the distributor through trolley operating in fully gurarded feed rail running overhead and parallel to the plating line.

Copper shot is added to the distributor hopper with tilting bucket on a monorail hoist. The bucket is filled in the raw material storage area on the main floor, raised with an electric hoist to the plating deck and moved on monorail track to dumping position over the distributor hopper.

FINISHED WIRE HANDLING

The spools of plated wire removed from the take-up stands are rolled onto a chock-strip in the operating aisle centrally between the two take-up stand lines. This strip serves as a temporary storage and spots the finished wire spools directly under and overhead monorail. The spools are picked up from this strip with a hair-pin hook on a trolley-mounted electric hoist and pushed to a pallet-loading area at the open end of the take-up line. Each pallet holds four spools of wire, and both spools and pallets are of such size that four spools may be placed with a single spotting of the pallet. The pallets are of special design, double-sided and made for stacking. Loaded pallets can be stacked four deep, the upper pallets resting on the heads of the spools on the lower pallets. The spool heads are made of cast steel and are of ample strength to sustain this load.

The loaded skids are picked up with an electric fork truck and moved to the loading dock at the far end of the building. Here the loaded pallet is moved directly into a motor-tractor drawn van parked at one of 2 loading doors. The van holds one day's (24 hours) output of electroformed wire.

SAFETY FEATURES

The electroforming process involves the use of chemicals all of which are dangerous when taken internally. Many are corrosive to the skin and some form poisonous vapors and gases under abnormal conditions. Specifically, extensive use of acids and cyanides demanded that extreme care be exercised in the layout of chemical storage and handling areas associated with each unit process. To aid in preventing any accidental mixing of these compounds and the possible generation of lethal hydrocyanic acid gas, a number of safety features are embodied in the design of the machine. The more important of these features are the following:

1. Individual pits for isolating the storage, mixing and filtering equipment associated with each unit process have been installed. By this action any overflow from a storage reservoir or solution leak in the handling equipment of any unit process will be confined to its own pit and may be neutralized and flushed to sewer.

2. Whenever acid and cyanide compounds occupy adjacent locations in the chemical storage and handling area, chemically resistant protective barriers have been erected between them.

3. Air wipers, water wash cells, and steam wipers have been installed in the processing sections of the machine between each acid and cyanide

bath to effectively remove from the wire any dragout from one bath before it proceeds to the next.

The safety features thus far discussed are installed with a view toward preventing the accidental generation of hydrocyanic acid gas. Additional measures have been adopted to further protect the employee. Limited admission to the electroforming building is enforced and authorized identification cards are issued only to engineering, operating and maintenance personnel assigned to the process. By such action the possibility of injury to the unacquainted observer is eliminated. Protective face shields are required equipment, they are stored on racks at the main entrance to the building and are available to all personnel. Safety showers have been strategically located throughout the building. Gas masks have been provided and are readily available at three locations. These masks are the self generation type, they will provide oxygen regardless of the nature of the surrounding atmosphere. Emergency machine shut-down buttons have been installed at four positions in the building. Finally, an evacuation alarm system has been installed for use of personnel in the building in case of an accident or failure of equipment that would result in the generation of hydrocyanic acid gas. The system includes three push-buttons under glass, one at each entrance to the building and one on the machine control consoles. A siren is provided and is audible throughout the building. Operation of any one of these buttons will trip the 480-volt substation circuit breakers for all power feeders with the exception of the lighting and ventilation circuit breakers and completely shut down both machines including all associated auxiliary machinery. The siren will be sounded and annunciator drop will be operated together with a bell and indicating light in the Firehouse and Watch Service Organization.

PERSONNEL REQUIREMENTS

It may be of interest to note that in planning this installation careful attention has been given to the increasing shortage of labor and to the provisions of automatic control and mechanical aids to reduce the labor requirements.

No standard measuring stick being available to determine the result of the efforts to reduce labor, it can be said that in a building 340 feet by 91 feet containing two million dollars worth of equipment capable of manufacturing two million dollars worth of product a year on a 350- day 3-shift basis the total operating force is 21 (five men per shift plus a material handler on the day shift).

The project is essentially chemical requiring a considerable amount of both electrical and mechanical engineering and may be regarded as a

good example of what can be done by a team of interested and competent engineers. The entire project from conception thru development of process and design and construction of equipment was conducted by Western Electric engineers. The product was specified and checked as to properties and electrical and mechanical requirements by Bell Telephone Laboratories.

The process as developed and operated is probably applicable to a number of other Bell System requirements which will be investigated and will form the basis for future expansion.